PAUL, WEISS, RIFKIND, WHARTON & GARRISON
1615 L STREET, NW WASHINGTON, DC 20036-5694
TELEPHONE (202) 223-7300
FACSIMILE (202) 223-7420

1285 AVENUE OF THE AMERICAS
NEW YORK, NY 10019-6064

199, BOULEVARD SAINT-GERMAIN
75007 PARIS, FRANCE

AKASAKA TWIN TOWER
17-22, AKASAKA 2-CHOME
MINATO-KU, TOKYO 107, JAPAN

SUITE 1910 SCITE TOWER
22 JIANGUOMENWAI DAJIE
BEIJING, 100004
PEOPLE'S REPUBLIC OF CHINA

13TH FLOOR, HONG KONG CLUB BUILDING
3A CHATER ROAD CENTRAL, HONG KONG

JEFFREY H. OLSON
COMMUNICATIONS COUNSEL
(202) 223-7326

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December 15, 1999

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Magalie Roman Salas, Secretary
Federal Communications Commission
445 12th St., S.W., Room TW-B204
Washington, D.C. 20554

Re: Written *Ex Parte* Communication in ET Docket Nos. 98-206, RM-9147, and RM-9245

Dear Ms. Salas:

This letter is submitted in response to an *ex parte* communication submitted by Northpoint Technology, Ltd. ("Northpoint") in the above-referenced docket on November 12, 1999. In its filing, Northpoint cites to a contribution from France to ITU-R WP 4-9S, dated April 14, 1999 ("Document 4-9S/126"), which discusses a possible method for sharing spectrum ("Dynamic Channel Assignment" or "DCA") among the terrestrial Fixed Service ("FS") and the Fixed-Satellite Service ("FSS") in the 18.8-19.3 GHz band ("18 GHz band"). Northpoint appears to be suggesting that the DCA concept discussed therein supports a scheme proposed by Northpoint for sharing between Non-Geostationary Orbit ("NGSO") FSS systems and the Northpoint system in the 12.2-12.7 GHz band (the "12 GHz band"). Put simply, Northpoint's reliance on this paper illustrates once again the lack of technical support for Northpoint's claim that it can coexist with NGSO FSS systems.

Document 4-9S/126 contains the results of a study which modeled the deployment of 18 GHz band point-to-point microwave links in the Paris region. Of critical import here, the model assumed the use of directive antennas. Northpoint's proposed 12 GHz point-to-multipoint system, on the other hand, proposes to use non-directive transmitting antennas. Obviously, there is a vast difference between the impact of a web of directional point-to-point microwave links on a co-frequency satellite system and the impact of Northpoint's proposed point-to-multipoint transmissions, that are intended to cover the entirety of each service area. The results of the studies contained in Document 4-9S/126 are patently inapposite to assessing the feasibility of sharing

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between ubiquitous NGSO FSS user terminals and a high-density, point-to-multipoint Northpoint-type system, and Northpoint knows this to be so.[1/]

Indeed, in focusing on just that one French paper from among the many comprehensive studies of NGSO FSS/FS sharing undertaken by WP 4-9S and related ITU-R groups, Northpoint ignores the substantial and uncontradicted technical evidence submitted to that body that refutes its claims. For example, the effectiveness of mitigation techniques in the high density sharing environment contemplated by Northpoint was recently addressed in a contribution by the United States to the Conference Preparatory Meeting ("CPM") held in Geneva in November 1999.[2/] As explained in that document, "as the deployment density of either service [FS or FSS] increases, proposed interference mitigation techniques rapidly become ineffective." This U.S. proposal to the CPM concluded that "frequency sharing between FS and FSS in the same geographic area is difficult if either service deploys large numbers of stations."

Northpoint's selective reliance on WP 4-95 papers is further illustrated by the fact that, in the very same study group that considered the French paper relied on by Northpoint, Teledesic Spain submitted Document 4-9S/196,[3/] which analyzes some of the burdens that implementation of DCA would have on a typical broadband satellite system in the more limited interference environment there under consideration. This study concludes that the resulting reduction in network capacity and quality of service, and the

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1/ SkyBridge has on several prior occasions called Northpoint to task for its repeated failure to acknowledge this basic technical fact. See, e.g., Letter from Jeffrey H. Olson to Magalie Roman Salas, dated November 10, 1999 (detailing the difficulties in sharing between ubiquitous NGSO FSS user terminals and high density, point-to-multipoint, terrestrials systems such as Northpoint). As SkyBridge has explained before, there is no particular dispute as to whether Dynamic Channel Assignment may be technically feasible and even useful to facilitate sharing in certain circumstances. See Opposition of SkyBridge L.L.C., File Nos. SAT-AMD-19980630-00056; SAT-AMD-19990108-00004, filed August 4, 1999, at 25. However, for the technical reasons given in this letter and in SkyBridge's numerous prior discussions of this issue in this docket, the scenario contemplated by Northpoint in the 12 GHz band is not such a case.

2/ Document CPM99-2/31, "Modifications to Section 3.1.4.3 of the Draft CPM-99 Report Regarding Sharing Between Non-GSO Earth Stations and FS Stations," United States of America, October 28, 1999 (a copy is attached).

3/ Document 4-9S/169, "Analysis of the Impact of Implementing Dynamic Channel Assignment (DCA) in NGSO FSS Systems," Teledesic Communications Spain, April 20, 1999 (a copy is attached).

necessary increase in satellite power and mass to attempt to offset that impact, can result in an essentially nonviable satellite system. Indeed, even the French document relied on by Northpoint emphasizes that "[t]he technical feasibility of these Dynamic Channel Assignment techniques hasn't been proved."[4/]

As SkyBridge has demonstrated throughout this proceeding, conducting a meaningful sharing analysis is a serious undertaking requiring strict technical rigor. Northpoint seems to prefer a more relaxed approach to these issues, not wishing to have its advocacy constrained by fundamental technical truths or inconvenient contrary evidence. Its conduct in this regard is perhaps the best evidence of the fact that Northpoint's proposed system would cause substantial and debilitating interference to co-frequency NGSO FSS systems.

If there are any questions regarding this matter, please contact the undersigned.

Respectfully submitted,

Jeffrey H. Olson
Diane C. Gaylor
Attorneys for
SkyBridge LLC

cc: Dale Hatfield
Julius Knapp
Thomas Derenge
Don Abelson
Thomas Tycz
Thomas Sugrue
Thomas Stanley
Ari Fitzgerald
Peter Tenhula
Adam Krinsky
Mark Schneider
Bryan Tramont

4/ Document 4-9S/126, at 7.

INTERNATIONAL TELECOMMUNICATION UNION
RADIOCOMMUNICATION SECTOR

CONFERENCE PREPARATORY MEETING FOR WRC-2000

GENEVA, 15 - 26 NOVEMBER 1999

Delayed Contribution
Document CPM99-2/31-E
28 October 1999
Original: English

Received: 28 October 1999

United States of America

MODIFICATIONS TO SECTION 3.1.4.3 OF THE DRAFT CPM-99 REPORT REGARDING SHARING BETWEEN NON-GSO FSS EARTH STATIONS AND FS STATIONS

(WRC-2000 AGENDA ITEM 1.13)

1 Introduction

The purpose of this contribution is to propose modifications to the draft text for section 3.1.4.3 of the CPM-99 Report addressing sharing between FS and non-GSO FSS in the bands identified by Resolution 130 at WRC-97. Chapter 3 of the CPM-99 Report is entitled "Non-GSO FSS issues (WRC-2000 agenda item 1.13)."

The first addition is supported by studies performed in WP 4-9S as reflected in the following quotes from the most recent WP 4-9S Chairperson's Report (Document 4-9S/178):

4-9S/178 Report [4-9S/ES.NGSO18]:

§ 4.1, p. 148

> *"[ATPC] could potentially reduce the size of the exclusion zones created by FS transmitters during clear sky conditions, but would not sufficiently reduce the areas to permit ubiquitous deployment of NGSO FSS user terminals."*

§ 4.2, p. 150

> *"In addition to all the hardware, network and quality of service (QoS) impacts of the implementation of DCA, any theoretical potential of this technique to facilitate sharing between FS and broadband NGSO FSS systems would be eliminated as the number of FS assignments in the 18.8-19.3 GHz band continues to grow."*

§ 4.7, p. 157

> *"Although quite feasible for large earth stations, coordination is not practicable for low-cost, ubiquitous user terminals. The cost and administrative burden of implementing coordination would be out of proportion to the low cost and ease of deployment of these small user terminals."*

The proposal to add a final paragraph is intended to add a summary and make clear the fact that, except in special cases involving border regions, this is a national issue.

2 Proposed modifications

For convenience, the entire text of section 3.1.4.3 of the draft CPM-99 Report is reproduced in this section. The proposed additions are indicated with double underlining.

MOD **Sharing between non-GSO FSS earth stations and fixed-service stations**

The deployment needs of viable FS and FSS services range from sparse, low density to increasingly higher density. This affects the sharing conditions in terms of coordination between fixed stations and FSS earth stations. At one extreme is the low-density deployment of both services, which facilitates sharing. At the other extreme is the high-density deployment of both services, which creates the most difficult sharing environment. In this instance, either one or both services may be excessively constrained or prevented from offering a viable service in the same geographical area.

In the 10-30 GHz range, the fixed service applications are rapidly evolving to support cellular and PCS infrastructures as well as direct access to business and residential subscribers. There are also proposals for high-density FSS earth station applications. Some administrations are considering the authorization of such systems using area-wide (blanket) licensing. Such licensing schemes lead to a requirement for new approaches in order to facilitate sharing.

The case of sharing between FS and non-ubiquitous FSS earth stations can be handled through classical case-by-case coordination procedures which have already proved to work successfully. In the case of deployment of ubiquitous FSS terminals, in principle, the use of mitigation techniques by one or both services improves the ability of those services to share the same frequency bands. The feasibility of potential mitigation techniques and their relative effectiveness are currently being studied. This involves a wide range of technical, economic and regulatory trade-offs. Furthermore, it has been shown that as the deployment density of either service increases, proposed interference mitigation techniques rapidly become ineffective. In cases where mitigation is insufficient or not practicable in those bands that are already or planned to be heavily used by the one type of service, possible solutions range from frequency separation to constraining the introduction of the other type of service to low-density, non-ubiquitous applications.

Reasons: The addition is necessary to reflect studies performed in WP 4-9S as contained in the most recent WP 4-9S Chairperson's Report (Document 4-9S/178) as summarized in section 1.

In summary, frequency sharing between FS and FSS in the same geographic area is difficult if either service deploys large numbers of stations. However, this is a national issue except in the vicinity of international borders, where coordination between administrations may be required.

Reasons: Clarify the conclusion and bring forward the fact that, except in special cases involving border regions, this is a national issue.

INTERNATIONAL TELECOMMUNICATION UNION

RADIOCOMMUNICATION STUDY GROUPS

Delayed Contribution
Document 4-9S/169-E
20 April 1999
Original: English only

Teledesic Communications Spain

ANALYSIS OF THE IMPACT OF IMPLEMENTING DYNAMIC CHANNEL ASSIGNMENT (DCA) IN NGSO FSS SYSTEMS

I Introduction

Sharing studies carried out up to now have identified a potential of interference between Point-to-Point FS and FSS. After consideration of a number of studies on the issue of sharing between FS and NGSO FSS User Terminals at 18.8 - 19.3 GHz, using statistical and deterministic approaches, it has been concluded that the extent of the interference depends on the location and size of the considered geographical area. The sharing problems are most severe in urban areas where the FS deployment is or will be dense in the future and where a high number of NGSO FSS User Terminals is expected.

Furthermore, it has been concluded that coexistence of terrestrial Fixed Services (FS) and non-Geostationary Orbit (NGSO) Fixed Satellite Services (FSS) in the 18.8 - 19.3 GHz band could prohibit the reliable operation of the downlink in the NGSO systems. Specifically, each FS transmitter in this frequency band causes an exclusion zone inside of which NGSO FSS user terminals can receive harmful interference. To address this problem, some possible techniques to mitigate the FS interference into NGSO FSS receiving user terminals have been proposed.

Previous studies have discussed one potential mitigation technique referred to as Dynamic Channel Assignment (DCA) that has been proposed as a potential mechanism to facilitate sharing between NGSO FSS and FS in the 18.8 - 19.3 GHz band. The basis of DCA is implementation of frequency division multiple access (FDMA) in combination with user terminal frequency channel selection based on the local FS interference environment. In theory, if the FS deployment is limited and the number of FSS downlink channels (N) is large enough, every FSS terminal should be able to find at least a single channel that is below its FS interference threshold. Thus on the basis of site blocking due to severe interference, DCA would seem to theoretically provide some sharing potential. The potential effectiveness of this technique from the point of view of technical compatibility advantages to facilitate sharing between FS and NGSO FSS is still being studied and debated.

This document addresses only the implication on FSS networks of implementing DCA. However, to understand the overall scope of implementing a mitigation technique like DCA, it is necessary to refer to the previous studies made on its potentialities for improving the interference scenario.

It has to be borne in mind that any sort of DCA mitigation technique is based on a reduction of capacity from the NGSO FSS network and the fact that the technique would not be effective if not accompanied by appropriate FS frequency channel assignment procedures. This conclusion is endorsed by studies, stating that although the identified mitigation technique could theoretically improve the sharing situation and resolve a certain percentage of interference cases, there could still be areas where this mitigation technique would not be sufficient to meet the availability requirements of FSS systems. In addition, when implementing Dynamic Channel Assignment, an assignment algorithm has to be determined too. The assignment algorithm is responsible for the channel distribution among users. The larger the number of users in the network the less realistic to achieve an optimum channel assignment. As an example, simple terminal-based algorithms, as the one used in DECT, may introduce a 20% traffic loss in addition to the significant traffic loss due to statistical multiplexing considerations as shown below. Simulations show that NGSO FSS traffic capacity is severely decreased when the number of FS transmitters within a given geographic area increases. Moreover, simulations show that a small number of FS links within a typical NGSO FSS cell causes DCA failure, and complete blockage of some FSS terminals. Therefore, if no FS Frequency Management is adopted DCA will not be operative because of its inherent limitation in handling an increasing number of interference sources.

Notwithstanding the above problems for the DCA effectiveness from the sharing capabilities point of view, this contribution describes an extensive analysis that was carried out to explore the potential of any sort of DCA technique with respect to its feasibility of implementation in a NGSO FSS network. Some of the problems with DCA reside with the growth in complexity of the satellite and user equipment hardware and the ability of that hardware to efficiently meet demand for communications services. This paper examines some of the impacts that DCA would have on the following aspects of NGSO FSS systems:

1) Space segment (satellite mass, power and complexity).

2) Earth stations (user equipment size and complexity).

3) Network aspects (system capacity; QoS; operational complexity).

II Impacts to NGSO FSS space segment

1 Baseline Satellite hardware architecture (No DCA)

To analyse some of the impacts to the NGSO FSS system, it is necessary to define a baseline architecture to provide a basis for comparison. We define here as a baseline, a realistic NGSO FSS satellite architecture, in which satellite resources are optimized by using a moderate number of single carrier beams with a time division multiple access (TDMA) method. This design is very efficient for packet-based networks enabling the system to provide bandwidth on demand and accommodate the bursty nature (highly variable data rates) of broadband applications in which the ratio of peak to average traffic rate demand can be quite large.

The satellite transmission subsystem of the example baseline NGSO FSS system is shown in Figure 1. This architecture has a moderate number, M, of steerable, full-bandwidth downlink beams, each requiring just one modulator (e.g., one 500 MHz carrier per beam). Each downlink beam on the space vehicle (SV) is time-division multiplexed among multiple users and can point to any user in any cell within the satellite footprint. There are a large number of addressable cells within the SV footprint. For the purpose of this study, let us assume there are 20,000 addressable cells within the footprint of a SV, and the number of beams, M, is limited to less than 25. Further, assume a multiplexing factor of k users per beam.

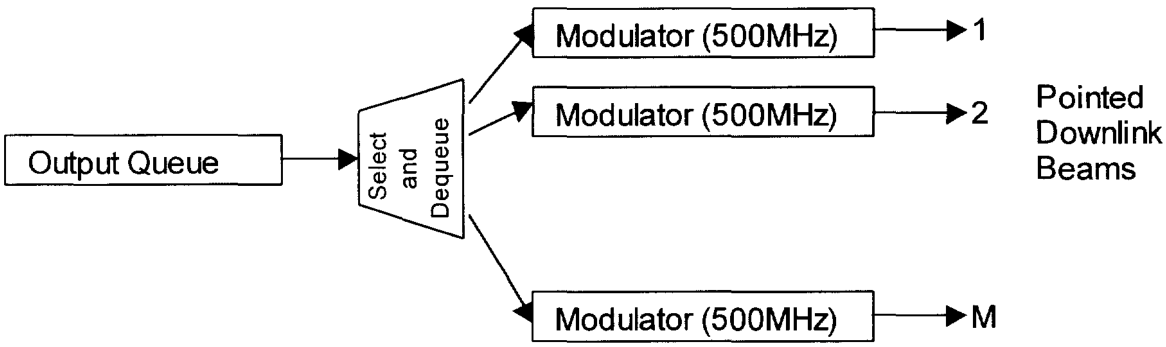

Figure 1: Baseline SV Queueing and Downlink Subsystem

Communications traffic that arrives at the SV is placed on the output queue, and when it reaches the head of the queue, it is removed and placed into a modulator for downlink. In order to meet Quality of Service (QoS) delay requirements, only a limited number of packets at the head of the queue are eligible for downlinking. These packets are selected and allocated to the modulators in such a manner as to minimize the interference between beams.

Figure 1a shows more detail of the RF satellite transmission path from the modulators to the antenna elements.

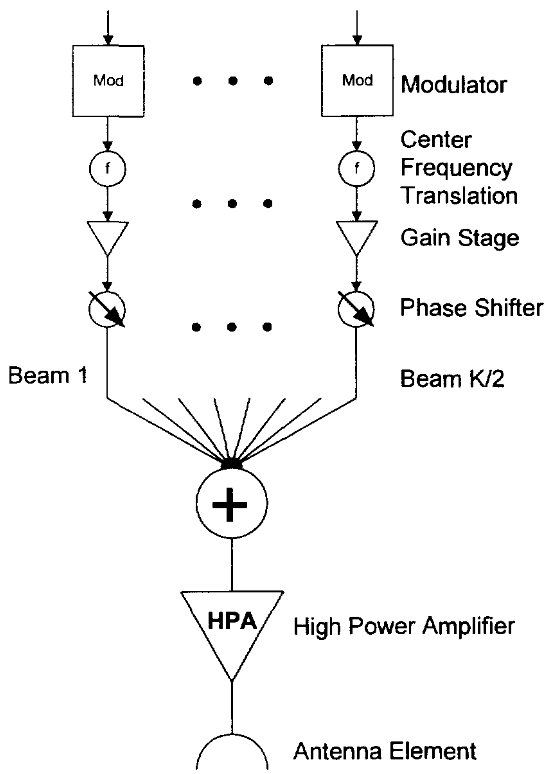

Figure 1a. The RF Hardware for a Non-DCA Baseline Satellite Architecture

2 Satellite architecture options for DCA

Implementation of DCA requires either multiple carriers per beam or significantly more beams per SV. The following two sections address these two DCA implementation options where it is assumed that the full NGSO downlink bandwidth is divided among N channels. Option 1 uses N carriers on each of the M beams, while Option 2 uses N times M beams, each with a single carrier of bandwidth (500/N) MHz.

3 DCA Satellite hardware architecture Option 1: N frequency channels per beam

In the DCA Option 1 satellite architecture, each beam has the ability to operate N channels simultaneously. Relative to the baseline, this requires replacing the full-rate modulators assigned to each beam with N modulators running at 1/N rate, where each modulator serves a smaller sub-band, or channel, in the 500 MHz frequency band. The N channels within a beam can serve up to N UEs simultaneously, but any UE receives only a single frequency channel at a time. In this scheme, each channel requires a packet transmission time that is N times longer than the baseline design. Therefore, with DCA Option 1, the peak data rate available to any user falls to 1/N times the peak data rate of the baseline system.

The output selection process consists of finding the first traffic packet in the output queue that satisfies the downlink self-interference rules. Once the first packet has been selected for a beam, additional packets can be selected as long as they are addressed to the same downlink cell and are on a different frequency than packets already selected for downlink within this beam.

This option suffers from several problems. The first problem is determining which channel to use for a particular user. There must be some network level messaging and an implementation that determines which channel to use for each user packet. There are several potential implementations, but all of them have a SV impact in additional hardware to determine the proper channel for user traffic (not to mention additional network overhead and capacity losses).

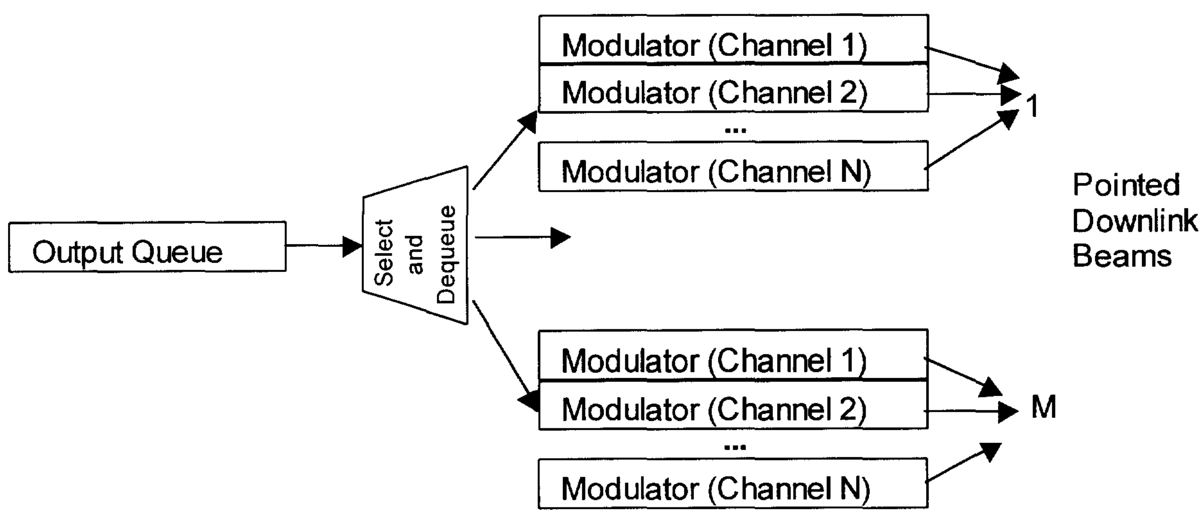

Figure 2: SV Downlink Subsystem with Multiple Channels per Beam

Single output queue implications with Option 1

There is also a larger problem with the single output queue. The problem is finding traffic that can make use of the multiple modulators within the same beam. After the first packet and its destination cell has been selected for a particular beam, the selection process will need to search through the packets at the front of the Output Queue looking for additional traffic that is addressed to the same cell (it is assumed that the downlink beam points to and covers only one cell at a time). The probability of finding additional traffic addressed to the same cell depends on L, the number of available candidates at the head of the Output Queue (generally $L<50$ to meet QoS delay requirements), and the number of possible addressable cells (on the order of 20,000). Thus the probability of finding a second traffic packet addressed to the same cell within the limited number of entries at the head of the Output Queue is very small (less than 2.5E-3)[1]. This implies that the additional modulators in the beam largely go unused and the resulting capacity would be very close to 1/N of the original capacity.

Multiple output queues implications with Option 1

To address the selection problem associated with a single output queue, multiple output queues could theoretically be implemented, with each output queue serving a single target cell and frequency channel. This would result in over 20,000*N queues, each of which requires system memory to manage. The memory needed for managing these queues would be proportional to the number of queues. Note this memory must be hardened to survive in the SV's radiation environment and is therefore costly. In addition, there would be significant processing overhead in determining the proper priority and service order of these queues. The memory cost and processing overhead of managing this number of queues and the processing overhead of managing the queue's priorities translate to significant increases in satellite mass and power, making this an infeasible solution.

An alternative to the single output queue implementation described above is to employ multiple output queues. Unfortunately this also results in a dramatic increase in the network hardware complexity required to manage the downlink resources. For efficient use of the beams the downlink data packets could be queued by downlink cell. This increases the memory and computational resources required on the satellite by several orders of magnitude. All the queues on the downlink utilize a common block of memory. Pointers are used to manage the different queues. Every new queue will require additional memory to store these pointers and additional computational resources for managing these pointers.

Consider again the design where each satellite serves 20,000 downlink cells. For each downlink cell there will be queues for two possible polarizations and four different packet priorities as well for the N different frequency channels for a total of 160,000 queues per frequency channel:

$$Q_{DCA1} = 2 \times 4 \times 20{,}000 \times N = 160{,}000N$$

This is a dramatic increase in complexity over the non-DCA architecture in which the packets are queued by the M downlink beams:

$$Q_{NONDCA} = 4 \times M = 4M$$

---

[1] If p is the probability that the addresses of two packets match ($p=1/20{,}000$ for a uniform traffic distribution), then $(1-p)^L$ is the probability that none of the addresses match. With a binomial expansion, $(1-p)^L > 1-Lp$ and thus the probability of having matches is less than Lp=2.5E-3.

Satellite RF hardware increases with Option 1

Figure 2a below illustrates the growth of components in the satellite downlink RF hardware when the number of channels, N, equals just four. To support the operation of the N channels, each beam must increase its RF components by a factor of N relative to the non-DCA baseline architecture. In addition, a new level of RF combiners is required to combine the signals from the different frequency channels on each of the downlink beams.

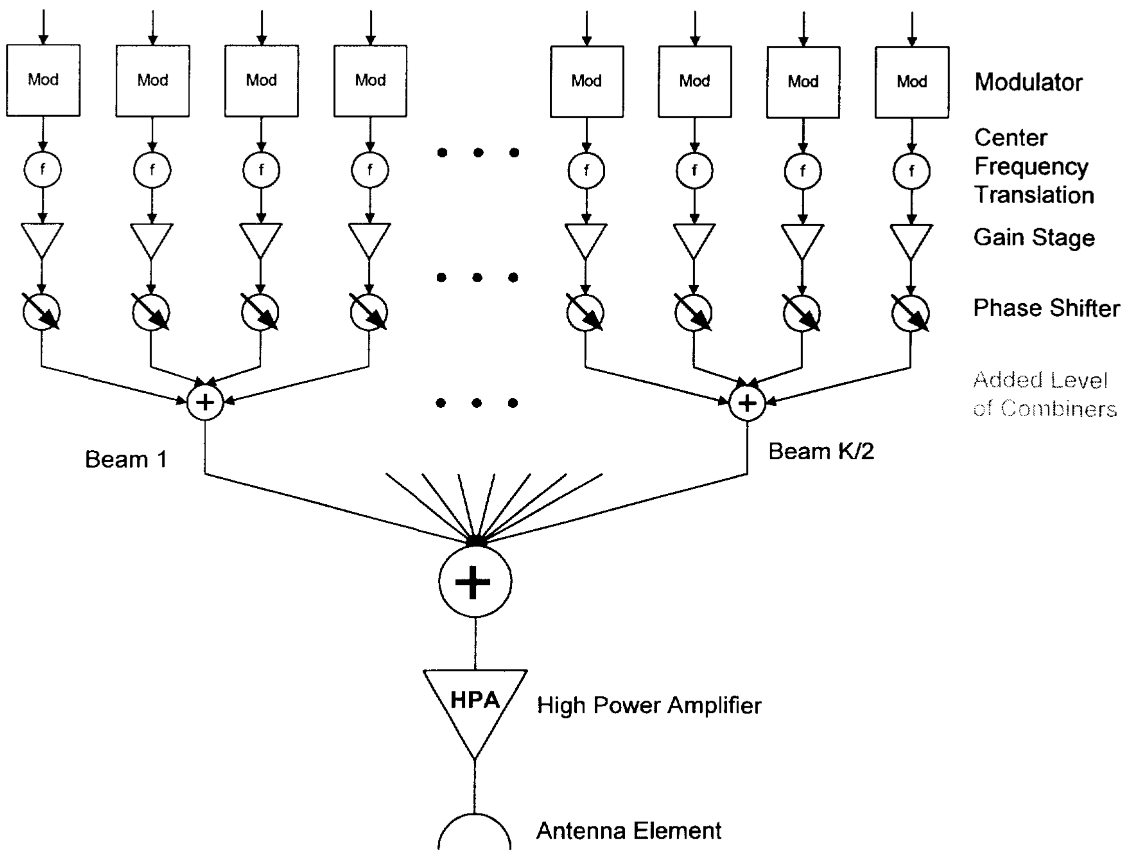

Figure 2a. Satellite Downlink RF Architecture of DCA Option 1

4 DCA Satellite hardware architecture Option 2: N times the number of beams

DCA Option 2 satellite architecture provides a method of avoiding the dramatic increase in number of queues experienced with satellite hardware architecture for Option 1. This is achieved by increasing the number of beams instead increasing of the number of carriers per beam. Each beam retains just a single carrier and therefore only one modulator is required per beam. It is assumed each modulator can support any one of the N possible channels for a given beam. In an attempt to retain as much of the original downlink capacity as possible, there would need to be at least N times the original number of beams (N*M total beams per satellite). Due to beam packing inefficiencies and other capacity loss mechanisms, it would be extremely difficult to retain the original capacity even with more than N*M beams.

Single output queue implications with Option 2

The output selection process for Option 2 is the same as Option 1 in that it would search through a limited number of packets at the head of the output queue that meet the self-interference constraints on beam pointing (e.g., minimum frequency re-use distance). However, due to the fact that there are more beams, the "limited number" of packets considered would need to be increased proportionally. The selection process would require more processing power, with the throughput requirements increasing by a factor proportional to N*M.

This change avoids the problem imposed by a requirement to find multiple packets addressed to the same cell, by using multiple independent beams. If there are multiple traffic packets near the head of the output queue addressed to the same cell, they can be selected to be transmitted on different beams (as long as they are on different channels and satisfy the downlink self-interference constraints).

This does add a requirement that each ground station be able to receive on all channels simultaneously in order to maintain the baseline system's capability to deliver a full 500 MHz capacity to a single user, wherever its location does not prevent it from receiving over the full 500 MHz band. This however, would result in a large impact to ground stations.

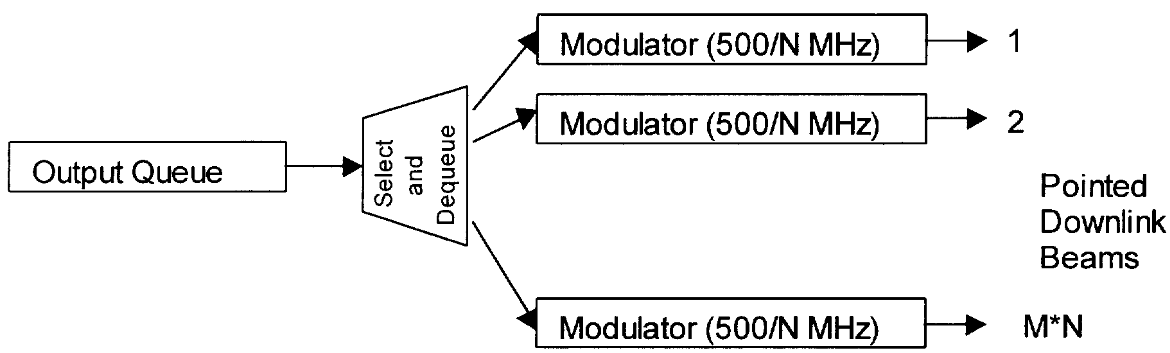

Figure 3: SV Downlink Subsystem with Additional Beams

Multiple output queue implications with Option 2

With Option 2, besides the multiplicative increase in RF hardware complexity, there is also a moderate growth in the hardware to support network functions required for the multiple output queue alternative. The management of the additional beams increases the requirements on the satellite memory and processing power. There is still an increase in the number of queues required to support this design over the non-DCA design. Even though there is not a need to queue by cell as with the multiple queue alternative in Option 1, the increase in number of beams creates additional queues. Each beam must have a queue for the four packet priorities, so the total number of queues is increased by a factor of N over the non-DCA case:

$$Q_{DCA2} = 4 \times M \times \mathrm{N} = 4M\mathrm{N}$$

Satellite transmit antenna complexity

Furthermore, there is a large increase in the SV's antennae complexity resulting in a large mass increase to support multiple beams. If we assume the downlink antennae subsystem is 25% of the mass of the SV and if we assume the antennae mass increases by a factor of N/2, then the total mass increase would be N/8 resulting in a new SV mass of (1+N/8)*Old_Mass. For N=8, this would result in a 100% increase in total SV mass. Even for only four channels (N=4), the mass increase would be 50%, which would also be unacceptable from a launch budget standpoint.

Satellite RF hardware increases with Option 2

Satellite RF hardware architecture for DCA Option 2 trades the large complexity of the network hardware in the first design for a large growth in RF hardware. In addition to the significant impact on the selection process, the SV would need N times the original modulators and N times the original number of beams. There would be a satellite power increase due to additional modulators and due to the increased number of beams. Specifically, each satellite must now support N times the amount of downlink RF hardware. Each of the additional beams must have its own modulator, its own oscillators, phase shifters, power combiner, power amplifier, etc., as indicated in Figure 3a.

FIGURE 3A TO BE PROVIDED

(Figure 3a. Satellite Downlink RF Architecture of DCA Option 2)

III Impacts to NGSO FSS Earth Stations

Whether the satellite RF architecture to implement DCA corresponds to Option 1 or Option 2 above, the impact on the NGSO user equipment (UE) is substantially the same. Replacing the satellite transmitters' full rate modulators with N modulators running at 1/N rate in the SV (regardless of whether they are transmitted within the same beam or in N different beams) results in the corresponding replacement in the UE of the baseline full-rate demodulators with 1/N rate demodulators. An added complexity for the UE (and for the system) comes from determining which of the N channels the UE should monitor on. Additional addressing bits would have to be added for the UE so that the SV would know what default channel the UE normally monitors on. Otherwise, any UE would have to register with the SV even in monitor-only mode causing the SV indexing table to grow significantly. Balancing out the load on the default N channels would then be a computational task of the network control system. Of course, such a solution reduces the maximum data rate that could be received by a single user by a factor of (1/N).

In order to come as close as possible to maintaining the baseline peak rate capability, it would become necessary for a UE to receive simultaneously on all N channels. This is a significant increase in complexity. It would require N times as many down-converters, local oscillators, filters, A-to-D converters, demodulators, etc. In the event the UE is sited near a terrestrial source that interferes with one or more of the N channels, the maximum capacity that the UE could receive would be reduced by a factor of (N-x)/N, where x = number of blocked channels for that UE. A UE located near an interfering site would need to register the channel or channels with the network directory service and/or the serving SV to ensure that traffic was not sent in the interfering bands. This would waste further network resources by requiring more capacity to be used for overhead packets (non-user data).

For the UEs there is also the issue that adjacent channel self-interference might become a significant problem unless frequency guard bands are added between channels which would decrease bandwidth available for traffic. Without proportionate guard bands, the power level of the adjacent channel may be required to roll off at a rate that may impact SV costs significantly.

FIGURE 4 TO BE PROVIDED

(Figure 4. In Order to Receive at Peak Rate, the UE Must Employ Separate Receive Chains for Each Simultaneous Downlink Beam)

IV Some impacts to NGSO FSS network capacity

1 DCA effect on statistical multiplexing gain

This section analyzes the effects of DCA on the downlink capacity of NGSO FSS systems from a statistical multiplexing point of view and demonstrates that implementation of DCA results in a downlink capacity loss of potential significance depending on the scenario under consideration.

Broadband NGSO FSS networks will take advantage of the packet-switched environment by allowing a set of channels to be shared -- on a packet-by-packet basis -- among a large set of users, with capacity assigned on demand to meet the users' current needs. This is in contrast with dedicated channel assignment mechanisms typically implemented in circuit-switched systems. This flexibility allows an NGSO FSS network to efficiently handle a wide variety of user needs: from occasional use to full-time use; from low data rates to high data rates; from constant bit rate to highly variable bit rate. Such a mix of broadband traffic will inevitably lead to bursty traffic characteristics.

Reduction in statistical multiplexing efficiency with DCA

To effectively demonstrate the channelization effect that results from DCA on the downlink performance from a capacity standpoint, we appeal to two important mechanisms: statistical multiplexing and traffic aggregation. The first mechanism, statistical multiplexing, is a technique that allows for efficient resource utilization in packet-switched networks. Suppose a resource is used by a set of bursty sources that have an aggregate peak rate of p packets/second and an average rate of m packets/second. In the worst case, requests from all sources could arrive simultaneously, so a conservative resource allocation scheme is to serve them at a rate of p packets/second. This approach, however, is not efficient since the serveroperates below full capacity when less than p packets/second are arriving. A more viable approach would be to buffer some of the resource requests, and serve them at a rate C packets/second which is smaller than p, but larger than m. As C gets closer to p, the QoS (average delay or block rate) is reduced, but resources are wasted. On the other hand, a smaller C implies more efficient resource utilization, but results in QoS degradation, seen by the user as either an increase in average delay or an increase in block rate. Accordingly, given the level of QoS requested by the source, the appropriate value of C is computed to satisfy the request. In general, the ratio of the service rate C to the mean rate m required to maintain a specific level of QoS is proportional to the variance of the arriving traffic stream.

More specifically, we consider a self-similar traffic arrival process A_t, which denotes the amount of traffic offered in the time interval of length t:

$$A_t = mt + \sqrt{am}Z_t$$

We call the process fractional Brownian traffic if Z_t is a normalized fractional Brownian motion. The process has three parameters m, a, and H with the following definitions: m is the mean traffic arrival rate, a is a variance coefficient, and $.5 <= H < 1$ is the Hurst parameter of Z_t [Will Leland, Murad Taqqu, Walter Willinger, and Daniel Wilson, "On the Self-Similar Nature of Ethernet Traffic", IEEE/ACM Transactions on Networking, Vol.2, No.1, February 1994].

The Hurst parameter partially characterizes the burstiness of a traffic stream. Let $X = A_{t+1} - A_t$ be a covariance stationary stochastic process with a given mean and variance. If X has an autocorrelation function of the form:

$$r(k) \propto k^{-\beta} \text{ as } k \rightarrow \text{infinity}$$

where 0 < beta < 1, i.e. a hyperbolically decaying autocorrelation function, then the Hurst parameter, H, which quantifies the long range dependence characterization of the process X, is related to beta through $H = 1 - \beta/2$. Note that H has a lower bound of 0.5 and an upper bound of 1.0. Less bursty traffic streams typically have a Hurst parameter closer to 0.5 and more bursty traffic streams have a Hurst parameter closer to 1.0.

The traffic arrival process arrives into a buffer of size x. Our goal is to determine the service rate C such that the buffer overflow probability does not exceed ε (this constitutes the QoS specification). A lengthy derivation yields:

$$C = m + \left[\kappa(H)\sqrt{-2\ln\varepsilon}\right]^{1/H} a^{1/(2H)} x^{-(1-H)/H} m^{1/(2H)}$$

where:

$$\kappa(H) = H^H (1-H)^{1-H}$$

The above equation clearly demonstrates the proportionality of the required service rate C to the variance coefficient a for a fixed mean arrival rate m.

Reduction in traffic aggregation efficiency with DCA

The second mechanism, aggregation, is a simple consequence of the law of large numbers; aggregating more traffic sources results in decreased variability[2] of the aggregated traffic. In the above mathematical framework, as we aggregate traffic from more sources the variance coefficient a decreases.

The combination of these two mechanisms results in the following principle: If N traffic streams are arriving into a server of capacity C, it is much more efficient to apply this service rate to the aggregate of the traffic streams than to dedicate a portion C/N of the service rate to each of the arriving streams. In other words, more average traffic can be served at a given QoS with a single large server at service rate C, than with N servers each at service rate C/N.

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2 One measure of variability is the ratio of the variance to the mean.

2 Effect of DCA on downlink capacity and QoS

The DCA approach calls for partitioning the available bandwidth into N channels. We assume that ground terminals have knowledge of the channels that interfere with terrestrial FS services, and that this configuration is quasi-static, although in practice the interference scenario could be changing according to the FS commercial evolution. For illustrative purposes, we assume a modulation/coding scheme that results in a data rate of 300 Mbps in the available bandwidth. We will contrast the average capacity throughput carried by a single downlink beam with 1 x 300 Mbps, 2 x 150 Mbps, 3 x 100 Mbps, and 6 x 50 Mbps channel DCA under the following assumptions:

- Self-similar traffic arrival process with Hurst parameter $H = 0.8$
- Buffer size of 200 Mbytes
- Cell Loss Ratio specification of 10^{-7}

The resulting average capacity throughput is summarized in the following table:

Number of Channels per beam	No DCA	2 Channel DCA	3 Channel DCA	6 Channel DCA
Total Avg Capacity Throughput	162	139	124	100
Delay (ms)	X	1.7X	2.4X	4.1X

With 6 channel DCA, the above analysis indicates that with no DCA, a single channel downlink beam can carry a packet-based average traffic load of 162 Mbps, while a 6 channel downlink beam can carry a mean traffic load of 100 Mbps; **a capacity loss of 38%**. There is also an additional delay incurred as indicated in the table above since packets remain in queues longer due to the lower service rate.

Another specific example

Figures 2-4 demonstrate the principle with another specific example. Figure 2 shows an aggregate traffic stream served with a 300 Mbps channel. The QoS is defined in this case by the percentage of time that the traffic requests exceed the channel size. Here the required QoS is defined as a 1% block rate. Note that with packet traffic these "blocks" could be considered delays since the traffic may be buffered and served after the aggregate traffic level has subsided below the maximum channel size.

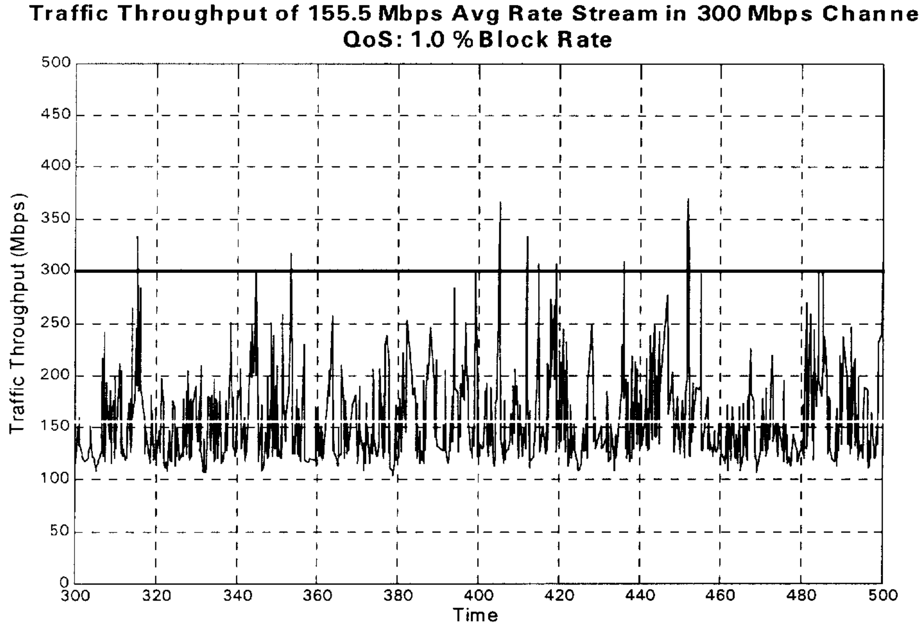

Figure 2. Traffic Throughput of 300 Mbps Channel with 1% Block Rate

Figure 3 shows the resulting QoS when the average traffic stream from Figure 2 is divided up into six separate traffic streams each with an average equal to one sixth of the original stream average. Each stream is served by a channel one sixth the original channel size. Note that the QoS of this stream has degraded significantly from an approximate block rate of 1% to a block rate of about 7.4%.

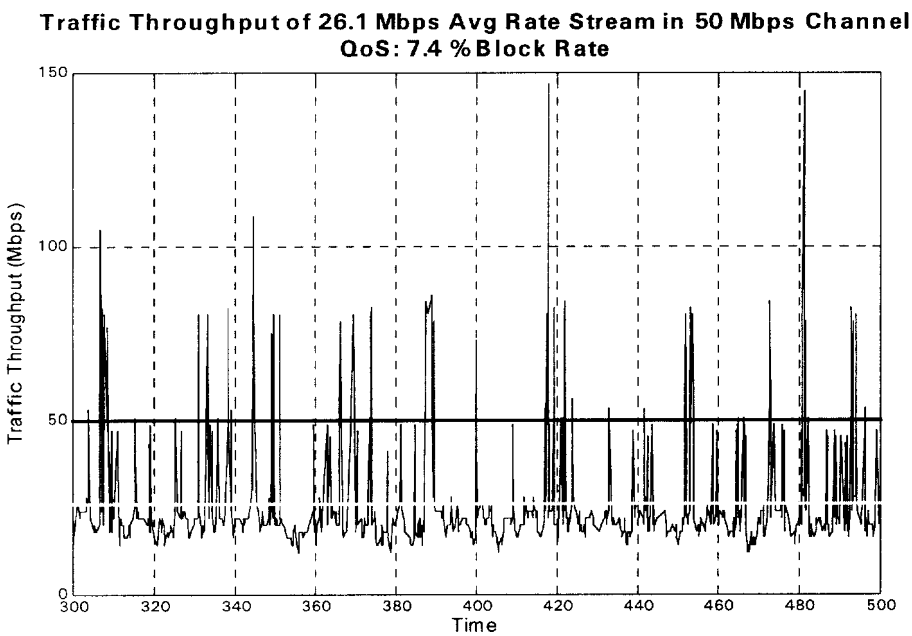

Figure 3. Traffic Throughput of 50 Mbps Channel with 7.4% Block Rate

Figure 4 demonstrates the loss in statistical multiplexing gain when channelizing a 300 Mbps channel into six separate 50 Mbps channels. In order to maintain the QoS level at a 1% block rate, the average traffic stream served by the 50 Mbps channel must be reduced from 26.1 Mbps to 15.5 Mbps. This is a 40% loss in average capacity throughput for this specific example.

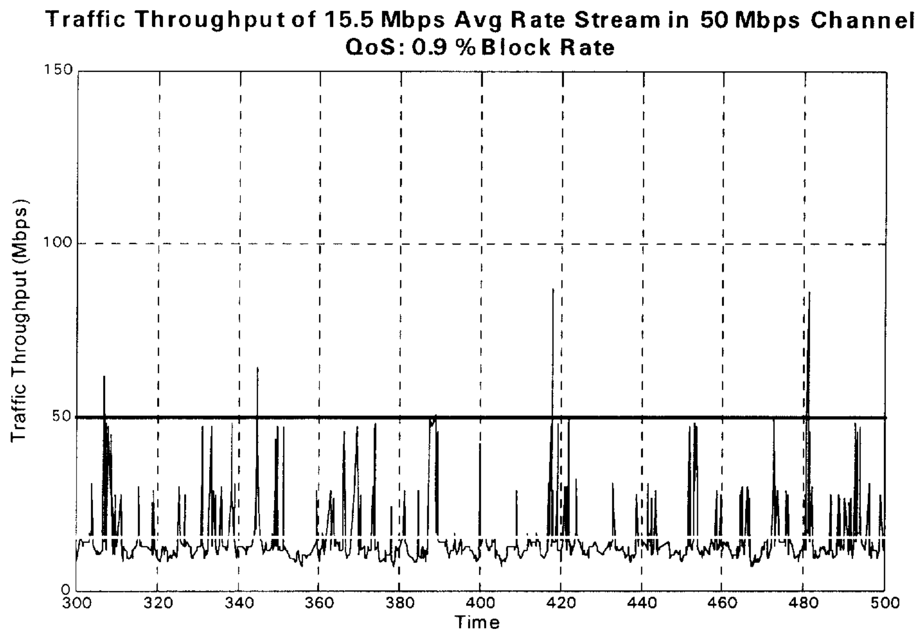

Figure 4 Traffic Throughput of 50 Mbps Channel with 0.9% Block Rate

V Conclusion

This paper has analysed just some of the many burdensome impacts that implementation of a Dynamic Channel Assignment technique would have on a typical broadband NGSO FSS system. For example, this study did not explore how an NGSO user terminal could detect the presence of FS interference -- a significant problem in its own right.

Relative to a system which does not perform DCA, a NGSO FSS system employing DCA on its downlinks would suffer significantly reduced network capacity (average and peak data rates) and reduced quality of service. For the N=6 channels example studied, it was shown that the capacity of an NGSO FSS system would be reduced by about 40% just due to statistical multpilexing considerations alone, with respect to a system not implementing any DCA mechanism. There would also be significant penalties in much higher satellite mass, power, and functional complexity. The impacts on the hardware of the spacecrafts would be such that the mass of a single NGSO FSS satellite would be increased in a range of 50% to 100%, depending on the number of channels implemented. Similarly, the power of the satellite would be significantly increased. Adding all these implications, the result of implementing a DCA technique would be the technological, operational and economical lack of capability to implement any NGSO FSS system realistically, because of its technological risks, inefficiencies, costs, launching difficulties, etc. In addition, UE cost and complexity would be greatly increased, thus departing from the implicit concept of availability of global NGSO FSS services to all users of all regions of the world.

It is to be further noted that this burden on an NGSO system would affect all of its users, including those located in countries or areas where the fixed service does not operate in the downlink frequency used by the satellite system.

Taken together, these factors alone result in the conclusion that implementation of DCA in NGSO FSS systems is not feasible.

In addition to all the hardware problems of the implementation of DCA, the theoretical potentialities of this technique are questioned by the natural evolution of FS assignments, its dynamism and their densities in a given area, rendering this technique as a theoretical mechanism not realiable for serious implementation in real and commercial NGSO FSS systems.